ZOOM LENS

Field of the invention

5   The present invention relates to a zoom lens suitable for small digital still cameras, video

cameras and the like equipped with image pickup devices such as CCD and the like, in particular, a

zoom lens suitable for small digital still cameras, video cameras and the like built into cellular

telephones, portable information terminals (PDA), etc.

10   **Description of the Related Art**

        In recent years, due to remarkable technical advancements in solid state image pickup

devices for uses in digital still cameras, video cameras and the like, small charge-coupled devices

("CCD") and similar devices are developed and, with it, a demand of smaller and lighter optical

systems are in great demand.

15   In particular, there is a need for smaller and thinner optical systems to be used on cellular

telephones and portable information terminals as they become smaller and thinner. The optical

systems used on the cellular telephones and portable information terminals of the prior art have

been relatively small and suitable for demands for smaller and thinner units because they were

fixed focal point lens systems.

20   In order to have a zoom lens that provides variable magnifying power on a cellular

telephone and a portable information terminal where a smaller and thinner unit is mandatory, it is

necessary to have a plurality of lens barrels that are arranged to be able to slide in and out and

cause them to collapse into the body when it is not in use in order to make the system thinner. The

constitution of the lens barrels, including the collapsible mount mechanism, becomes more complex as the number of components increases.

In order to improve the above situation, the present invention intends to provide a small, thin, and lighter zoom lens having a high quality optical capability suitable for being used on cellular telephones and portable information terminals, more specifically, a zoom lens having a zoom ratio of about 2, a depth direction stroke in the incidence direction of the object light between the in-use and the not-in-use (stored) conditions of less than 9 mm, and the longest dimension when it is in-use of less than 27 mm.

Summary of the invention

The zoom lens of the present invention comprises: a first lens group having a negative refractive power as a whole, a second lens group having a positive refractive power as a whole, and a third lens group having a positive refractive power as a whole, arranged in said order from object side to image side, for zooming from a wide-angle end to a telephoto end as well as correcting image surface changes required in accordance with said zooming by means of moving said second lens group and said third lens group from image side to object side; wherein said first lens group consists of a lens having a negative refractive power and a prism for changing a light path arranged in said order from the object side.

Since the depth dimension of the zoom lens according to said embodiment is the depth dimension in the direction the object light enters into the first lens group (a lens and a prism), it is possible to obtain a thin and small zoom lens wherein the depth dimension and the dimension

between the first lens group to the image surface remain constant regardless of whether it is used or not for shooting.

In the above embodiment, it is possible to adopt such a constitution wherein the second lens group consists of a lens with a positive refractive power and an aperture stop exists between the second lens group and the third lens group. In this embodiment, the total length in the optical axis direction becomes shorter and the lens groups on both sides (located on the upstream side and the downstream side) of the aperture stop can be formed in such a way as to have approximately identical external dimensions, so that the zoom lens can be made more compact efficiently.

In the above embodiment, it is possible to adopt such a constitution wherein the lens of the first lens group has an aspherical surface, the aspherical surface is formed on the surface with a smaller curvature radius, and the negative aspherical surface has a negative refractive power weakening toward its periphery. According to these embodiments, a better optical characteristic can be achieved as various aberrations can be easily corrected by having an aspherical surface, and distortion can be more easily corrected by having the aspherical surface on the surface with a smaller radius of curvature and forming it in such a way as to make the negative refractive power weaken toward the periphery.

In the above embodiment, said third lens group can be constituted to have at least one lens with a positive refractive power and at least one lens with a negative refractive power. According to said embodiment, various aberrations can be corrected with a better balance.

In the above embodiment, said third lens group can be constituted to have a lens at a position closest to the object having a positive refractive power and an aspherical surface at least on one side. According to said embodiment, spherical aberration can be corrected most suitably.

In the above embodiment, the prism of said first lens group can be formed to have an entrance surface and an exit surface both oblong in a direction perpendicular to a plane that includes an entrance axis and an exit axis. According to this embodiment, the zoom lens can be made thinner in the direction the object light enters (the direction of the optical axis from the first group's lens to the prism).

In the above embodiment, it is possible to adopt an embodiment that satisfies the following conditional formulas (1) and (2):

(1) $0.25 < |fw/f1| < 0.7$、

(2) $v1 > 40$、

where f1 is the focal length of the first lens group, fw is the focal length of the total lens system at the wide-angle end, and v1 is the Abbe number of the first lens group's lens. According to this embodiment, if the value of $|fw/f1|$ in the conditional formula (1) exceeds its lower limit, the refractive power of the lens of the first lens group becomes too small, so that a necessary back focus cannot be achieved; on the other hand, if it exceeds the upper limit, the back focus becomes too large, so that it becomes difficult to make the unit smaller as well as to correct astigmatism and coma aberrations. Therefore, by satisfying the conditional formula (1), a better optical characteristic and size reduction can be achieved. Also, by satisfying the conditional formula (2), lateral chromatic aberration can be corrected appropriately.

In the above embodiment, the first lens group, the second lens group, and the third lens group can all be made of resin materials. This embodiment makes it possible to manufacture easily, to reduce the manufacturing cost and to reduce the weight.

Brief description of the drawings

Fig. 1 is a drawing showing an embodiment of a zoom lens according to the present invention.

Fig. 2 (a) and (b) show the side views of the zoom lens shown in Fig. 1 at its wide-angle end and telephoto end.

Fig. 3 is a perspective view of the zoom lens shown in Fig. 1.

Fig. 4 (a), (b), (c) and (d) shows aberration charts of spherical aberration, astigmatization, distortion, and lateral chromatic aberration at the wide-angle end of the zoom lens according to the embodiment of Fig. 1.

Fig. 5 (a), (b), (c) and (d) shows aberration charts of spherical aberration, astigmatization, distortion, and lateral chromatic aberration at a middle position of the zoom lens according to the embodiment of Fig. 1.

Fig. 6 (a), (b), (c) and (d) shows aberration charts of spherical aberration, astigmatization, distortion, and lateral chromatic aberration at the telephoto end of the zoom lens according to the embodiment of Fig. 1.

Fig. 7 is a drawing showing another embodiment of a zoom lens according to the present invention.

Fig. 8 (a) and (b) show the side views of the zoom lens shown in Fig. 7 at its wide-angle end and telephoto end.

Fig. 9 (a), (b), (c) and (d) shows aberration charts of spherical aberration, astigmatization, distortion, and lateral chromatic aberration at the wide-angle end of the zoom lens according to the embodiment of Fig. 7.

Fig. 10 (a), (b), (c) and (d) shows aberration charts of spherical aberration, astigmatization, distortion, and lateral chromatic aberration at a middle position of the zoom lens according to the embodiment of Fig. 7.

Fig. 11 (a), (b), (c) and (d) shows aberration charts of spherical aberration, astigmatization, distortion, and lateral chromatic aberration at the telephoto end of the zoom lens according to the embodiment Fig. 7.

Fig. 12 is a drawing showing yet another embodiment of a zoom lens according to the present invention.

Fig. 13 (a) and (b) show the side views of the zoom lens shown in Fig. 12 at its wide-angle end and telephoto end.

Fig. 14 (a), (b), (c) and (d) shows aberration charts of spherical aberration, astigmatization, distortion, and lateral chromatic aberration at the wide-angle end of the zoom lens according to the embodiment of Fig. 12.

Fig. 15 (a), (b), (c) and (d) shows aberration charts of spherical aberration, astigmatization, distortion, and lateral chromatic aberration at a middle position of the zoom lens according to the embodiment of Fig. 12.

Fig. 16 (a), (b), (c) and (d) shows aberration charts of spherical aberration, astigmatization, distortion, and lateral chromatic aberration at the telephoto end of the zoom lens according to the embodiment of Fig. 12.

Description of numerical keys used in the drawings

I   First lens group

II   Second lens group

III   Third lens group

1   Lens (first lens group)

2   Prism (first lens group)

2a   Entrance surface

5   2b   Exit surface

L1   Entrance axis

L2   Exit axis

3. 3', 3''   Lens (second lens group)

4, 4', 4''   Lens (third lens group)

10   5, 5', 5''   Lens (third lens group)

6   Lens (third lens group)

7   Glass filter

8   Aperture stop

D1-D14   Surface distance on optical axis

15   R1-6, 8-15   Curvature radius

S1-S15   Surface

Preferred embodiment

A preferred embodiment of the present invention is described below referring to the

20   accompanying drawings.

Fig. 1 through Fig. 3 show a preferred embodiment of a zoom lens according to the present

invention, wherein Fig. 1 shows its basic constitution, Figs. 2 (a) and (b) show a side view of the

positional relations at the wide-angle and at the telephoto end, and Fig. 3 is a perspective view of the embodiment.

In this zoom lens, a first lens group (I) that has a negative refractive power as a whole, a second lens group (II) that has a positive refractive power as a whole and a third lens group (III) that has a positive refractive power as a whole are laid out in that order from the objective side to the image plane side as shown in Fig. 1.

The first lens group (I) consists of a lens 1 that has a negative refractive power and a prism 2 that changes the light path. The second lens group (II) consists of a lens 3 that has a positive refractive power. The third lens group (III) consists of a lens 4 that has a positive refractive power, a lens 5 that has a negative refractive power, and a lens 6 that has a positive or negative refractive power.

The lenses and the prisms that constitute the first lens group (1), the second lens group (II), and the third lens group (III) are all made of resin materials. As they are made of resin materials, they can light and inexpensive.

In the above embodiment, a glass filter 7 such as an infrared cut filter or a low pass filter is provided on the image side relative to lens 6 of the third lens group (III), and an aperture stop 8 is provided between the second lens group (II) and the third lens group (III), i.e., between lens 3 and lens 4. Since aperture 8 is located in the position as mentioned above, it is possible to make the lens groups arrange on both sides of it to have approximately equal outer diameters, thus reducing the size as a whole.

In the above embodiment, the second lens group (II) and the third lens group (III) move from the image surface.

e to the object side, in other words, from the wide-angle end shown in Fig. 2(a) to the telephoto end as shown in Fig. 2(b) to perform the zooming operation as well as to correct the image plane change caused by the zooming operation. Since the depth dimension D of the lens and the lateral total length H of the lens (distance from prism 2 of the first lens group (I) to the image plane) are

5   unchanged during the zooming operation, it can be easily mounted on cellular telephones, portable information terminals and the like where the mounting spaces are limited.

The focal length of the first lens group (I) is denoted f1, the focal length of the total lens system at the wide-angle end is fw, the focal length of the total lens system at the telephoto end is ft, and the focal length of the total lens system in the middle range is fm.

10   The surfaces of lens 1, prism 2, lens 3 through lens 6 are denoted Si (i = 1-6, 8-13), the radius of curvature of each surface Si is Ri (i = 1-6, 8-13), the refractive index relative to line "d" is Ni, and the Abbe number is vi (i = 1-6) as shown in Fig. 1.

As to glass filter 7, the surfaces are denoted Si (i = 14, 15), the curvature radius of surface Si is Ri (i = 14, 15), the refractive index relative to line "d" is N7, and the Abbe number as v7.

15   Further, each space (thickness, air gap) located between lens 1 and glass filter 7 along the optical axis is denoted Di (i = 1-14).

In prism 2, its entrance surface 2a and exit surface 2b are formed in rectangular shapes that are oblong in a direction perpendicular to a plane that contains entrance axis L1 and exit axis L2. In this case, the direction of the longer side of prism 2 and the direction of the longer side of image

20   pickup device (image plane) coincide with each other as shown in Fig. 3. As a result, the depth dimension D in the entrance axis L1 direction of the first lens group (I), i.e., the zoom lens, can be reduced, thus making the unit thinner.

A surface S2 with a smaller curvature radius between a surface S1 of the object side of lens 1 and surface S2 of image plane side is formed as an aspherical surface, wherein this aspherical surface is formed in such a way that its negative refractive power weakens toward the periphery. As a result, corrections of various aberrations, in particular, correction of distortion, can be

5 achieved.

A surface S5 on the object side of lens 3, a surface S8 on the object side of lens 4, and a surface S12 on the object side of lens 6 are formed as aspherical surfaces. Consequently, various aberrations can be adjusted in a good balance, and spherical aberrations can be corrected suitably, especially by forming surface S8 as an aspherical surface.

10 An aspherical surface can be expressed in the following formula:

$Z = Cy^2/[1+(1-\epsilon C^2 Y^2)^{1/2}] + Dy^4 + Ey^6 + Fy^8 + Gy^{10}$, where Z is the distance from the vertex of the aspherical surface to a point on the aspherical surface whose height from the optical axis is y; y is the height from the optical axis X; C is the ratio of curvature (1/R) at the vertex of the aspherical surface; ϵ is the conical constant, and D, E, F, and G are aspherical coefficients.

15 In the above embodiment, the first lens group (I) is formed to satisfy the following two formulas:

(1) $0.25 < |fw/f1| < 0.7$, and

(2) $v1 > 40$,

where f1 is the focal length of the first lens group (I), fw is the focal length of the total lens

20 system at the wide-angle end, and v1 is the Abbe number of the lens of the first lens group (I).

The conditional formula (1) defines the ratio of an appropriate focal length for the first lens group (I), where if the ratio exceeds the upper limit, the back focus becomes too large, so that it

becomes difficult to make the unit smaller as well as to correct astigmatism and coma aberrations; on the other hand if it exceeds its lower limit, the refractive power of lens 1 becomes too small, so that it becomes difficult to secure a necessary back focus. In other words, it is possible to achieve a satisfactory optical capability and reduce the size of the unit by satisfying this conditional formula

5   (1).

The conditional formula (2) defines the Abbe number of lens 1 that constitutes the first lens group (I), where if Abbe number is less than the lower limit it becomes difficult to correct the lateral chromatic aberration.   In other words, by satisfying the conditional formula (2), lateral chromatic aberration can be corrected appropriately.

10   As an example using specific numerical values of the above embodiment, an embodiment 1 will be shown below.   Table 1 shows the major dimensions of embodiment 1, Table 2 shows various numerical data (setup values), Table 3 shows numerical values of the aspheric surfaces, and Table 4 shows the focal length of the lens as a whole "f" (wide-angle end fw, middle position fm, and telephoto end ft) as well as numerical data concerning the spacing between the surfaces on

15   the axis D4, D6 and D13 at the wide-angle end, middle position, and telephoto end specifically.   In this example, the numerical data of the conditional formulas (1) and (2) are: $|fw/f1|=0.476$, fw$=3.350$ mm, f1$=-7.039$ mm, and $\nu1=56.4$

Figs. 4 (a)-(d), Fig. 5 (a)-(d) and Fig. 6 (a)-(d) are the aberration charts of spherical aberration, astigmatic aberration, distortion, and lateral chromatic aberration at the wide-angle end,

20   middle position, and telephoto end respectively.   In Fig. 4 (a) through Fig. 6 (d), Fig. 9 (a) through Fig. 11 (d), and Fig. 14 (a) through Fig. 16 (d), "d" denotes the aberration due to "d" line, "F" denotes the aberration due to "F" line, and "c" denotes the aberration due to "c" line, while

SC denotes the amount of dissatisfaction of the sine condition, DS denotes the aberration on the

sagittal plane, and DT denotes the aberration of the meridional plane.

5   Table 1

Object distance (mm)	Infinity(∞)	Thickness of third lens group (mm)	7.20
Focal length (mm)	3.35~ 5.00~ 6.43	Total lateral length (prism to image plane) mm	25.28
F number	2.89~ 3.41~ 3.94	Back focus (air conversion) (mm)	2.68~ 3.99~ 5.36
Total lens length (front of lens 1 to image surface) (mm)	28.23	Angle of view (2ω)	61.3°~ 40.0°~ 31.1°
Thickness of first lens group (depth) (mm)	7.75	Focal length f1 (mm)	-7.039
Thickness of second lens group (mm)	1.80	Wide-angle end focal length fw (mm)	3.350

Table 2

Surface	Curvature radius (mm)	Distance (mm)	Refractive index ("d" line)	Abbe number
S1	R1 -105.256	D1 1.250	N1 1.50914	ν1 56.4
S2*	R2 3.725			
		D2 1.700		
S3	R3 ∞	D3 4.800	N2 1.58385	ν2 30.3
S4	R4 ∞			
		D4 variable		
S5*	R5 14.566	D5 1.800	N3 1.50914	ν3 56.4
S6	R6 -13.487			
		D6 variable		
S7	Aperture stop			
		D7 0.000		
S8*	R8 4.291	D8 2.500	N4 1.50914	ν4 56.4
S9	R9 -27.904			
		D9 0.800		
S10	R10 -50.000	D10 1.500	N5 1.58385	ν5 30.3
S11	R11 6.916			
		D11 0.900		
S12*	R12 12.944	D12 1.500	N6 1.50914	ν6 56.4
S13	R13 14.260			
		D13 variable		
S14	R14 ∞	D14 1.200	N7 1.51680	ν7 64.2
S15	R15 ∞			

* Aspheric

Table 3

Aspherical surface coefficient		Numerical data
S2 surface	ϵ	1.0278000
	D	$-0.1581560 \times 10^{-2}$
	E	0.1204590×10^{-3}
	F	$-0.5290880 \times 10^{-5}$
	G	$-0.1085100 \times 10^{-5}$
S5 surface	ϵ	14.1500000
	D	0.9513050×10^{-4}
	E	0.4852330×10^{-4}
	F	$-0.2827050 \times 10^{-4}$
	G	$-0.1499290 \times 10^{-5}$
S8 surface	ϵ	0.0000000
	D	0.5818800×10^{-3}
	E	0.7729490×10^{-4}
	F	$-0.2913690 \times 10^{-5}$
	G	0.6163560×10^{-6}
S12 surface	ϵ	1.0000000
	D	$-0.6068020 \times 10^{-2}$
	E	$-0.6726320 \times 10^{-5}$
	F	0.1080110×10^{-4}
	G	$-0.2055410 \times 10^{-5}$

Table 4

	Wide-angle end	Middle position	Telephoto end
f (mm)	3.35 (fw)	5.00 (fm)	6.43 (ft)
D4 (mm)	7.395	3.367	1.264
D6 (mm)	1.000	3.713	4.450
D13 (mm)	0.885	2.200	3.567

(Back focus 1.00 mm)

5   In the above embodiment 1, lens depth D (lens 1 to prism 2) is 7.75 mm, total lens length

(prism to image surface) H is 25.28 mm, total lens length (front S1 of lens 1 to image surface) is

28.23 mm, back focus (air conversion) is 2.68 mm - 3.99 mm - 5.36 mm, F number is 2. 89 - 3.41

- 3.94, and angle of view (2ω) is 61.3° - 40.0° - 31.1°, thus providing a compact, thin, and a high

optical capability lens with all aberrations suitably corrected.

10   Fig. 7 and Fig. 8 show the basic constitution of a zoom lens of another embodiment

according to this invention. All components of this zoom lens are made of plastics (resins) and the

zoom lens is constituted similarly to the above mentioned embodiment except the changes made in

the specifications of lens 4', lens 5' and lens 6' of the third lens group (III).

As an example using specific numerical values of the above embodiment, an embodiment 2

15   will be shown below. Table 5 shows the major dimensions of embodiment 2, Table 6 shows

various numerical data (setup values), Table 7 shows numerical values of the aspheric surfaces,

and Table 8 shows the focal length of the lens as a whole "f" (wide-angle end fw, middle position

fm, and telephoto end ft) as well as numerical data concerning the spacing between the surfaces on

the axis D4, D6 and D13 at the wide-angle end, middle position, and telephoto end specifically. In this example, the numerical data of the conditional formulas are: $|fw/f1| = 0.476$, $fw = 3.350$ mm, $f1 = -7.039$ mm, and $v1 = 56.4$

Fig. 9 (a)-(d), Fig. 10 (a)-(d) and Fig. 11 (a)-(d) are the aberration charts of spherical aberration, astigmatic aberration, distortion, and lateral chromatic aberration at the wide-angle end, middle position, and telephoto end respectively.

Table 5

Object distance (mm)	Infinity (∞)	Thickness of third lens group (mm)	7.20
Focal length (mm)	3.35~ 5.00~ 6.43	Total lateral length (prism to image plane) mm	25.39
F number	2.89~ 3.43~ 3.98	Back focus (air conversion) (mm)	2.79~ 4.08~ 5.42
Total lens length (front of lens 1 to image surface) (mm)	28.34	Angle of view (2ω)	61.2°~ 39.9°~ 31.0°
Thickness of first lens group (depth) (mm))	7.75	Focal length f1 (mm)	-7.039
Thickness of second lens group (mm)	1.80	Wide-angle end focal length fw (mm)	3.350

Table 6

Surface	Curvature radius (mm)	Distance (mm)	Refractive index ("d" line)	Abbe number
S1	R1 -105.256	D1 1.250	N1 1.50914	v1 56.4
S2*	R2 3.725			
		D2 1.700		
S3	R3 ∞	D3 4.800	N2 1.58385	v2 30.3
S4	R4 ∞			
		D4 variable		
S5*	R5 14.566	D5 1.800	N3 1.50914	v3 56.4
S6	R6 -13.487			
		D6 variable		
S7	Aperture stop			
		D7 0.000		
S8*	R8 5.111	D8 2.500	N4 1.50914	v4 56.4
S9	R9 -33.812			
		D9 0.800		
S10	R10 12.088	D10 1.500	N5 1.58385	v5 30.3
S11	R11 5.889			
		D11 0.900		
S12*	R12 14.723	D12 1.500	N6 1.50914	v6 56.4
S13	R13 8.256			
		D13 variable		
S14	R14 ∞	D14 1.200	N7 1.51680	v7 64.2
S15	R15 ∞			

* Aspheric

Table 7

Aspherical surface coefficient		Numerical data
S2 surface	ϵ	1.1466000
	D	$-0.2082540 \times 10^{-2}$
	E	0.1196780×10^{-3}
	F	$-0.9545210 \times 10^{-5}$
	G	$-0.1047680 \times 10^{-5}$
S5 surface	ϵ	31.6600000
	D	$-0.6795480 \times 10^{-3}$
	E	$-0.1877220 \times 10^{-3}$
	F	$-0.1244610 \times 10^{-4}$
	G	0.3063120×10^{-6}
S8 surface	ϵ	-0.9200000
	D	0.1067690×10^{-2}
	E	0.9841570×10^{-4}
	F	$-0.9494250 \times 10^{-5}$
	G	0.8663850×10^{-6}
S12 surface	ϵ	1.0000000
	D	$-0.5542500 \times 10^{-2}$
	E	0.8034850×10^{-4}
	F	0.9776290×10^{-5}
	G	0.1975590×10^{-5}

Table 8

	Wide-angle end	Middle position	Telephoto end
f (mm)	3.35 (fw)	5.00 (fm)	6.43 (ft)
D4 (mm)	7.395	3.434	1.379
D6 (mm)	1.000	3.669	4.390
D13 (mm)	0.998	2.289	3.624

(Back focus 1.00 mm)

5   In the above embodiment 2, lens depth D (lens 1 to prism 2) is 7.75 mm, total lens length

(prism to image surface) H is 25.39 mm, total lens length (front S1 of lens 1 to image surface) is

28.34 mm, back focus (air conversion) is 2.79 mm – 4.08 mm - 5.42 mm, F number is 2. 89 -

3.43 - 3.98, and angle of view (2ω) is 61.2° – 39.9° – 31.0°, thus providing a compact, thin, and a

high optical capability lens with all aberrations suitably corrected.

10   Fig. 12 and Fig. 13 show basic constitutions of zoom lens of other embodiments according

to this invention. All components of this zoom lens are made of plastics (resins) and the zoom lens

is constituted similarly to the above mentioned embodiment except the changes made in the

specifications of lens 4", lens 5" and lens 6" of the third lens group (III).

As an example using specific numerical values of the above embodiment, an embodiment 3

15   will be shown below. Table 9 shows the major dimensions of embodiment 3, Table 10 shows

various numerical data (setup values), Table 11 shows numerical values of the aspheric surfaces,

and Table 12 shows the focal length of the lens as a whole "f" (wide-angle end fw, middle position

fm, and telephoto end ft) as well as numerical data concerning the spacing between the surfaces on

the axis D4, D6 and D13 at the wide-angle end, middle position, and telephoto end specifically. In this example, the numerical data of the conditional formulas (1) and (2) are: $|fw/f1| = 0.476$, $fw = 3.350$ mm, $f1 = -7.039$ mm, and $v1 = 56.4$

Fig. 14 (a)-(d), Fig. 15 (a)-(d) and Fig. 16 (a)-(d) are the aberration charts of spherical aberration, astigmatic aberration, distortion, and lateral chromatic aberration at the wide-angle end, middle position, and telephoto end respectively.

Table 9

Object distance (mm)	Infinity (∞)	Thickness of third lens group (mm)	7.20
Focal length (mm)	3.35~ 5.00~ 6.43	Total lateral length (prism to image plane) mm	25.35
F number	2.89~ 3.43~ 3.97	Back focus (air conversion) (mm)	2.75~ 4.04~ 5.37
Total lens length (front of lens 1 to image surface) (mm)	28.30	Angle of view (2ω)	61.1°~ 39.9°~ 31.0°
Thickness of first lens group (depth) (mm)	7.75	Focal length f1 (mm)	-7.039
Thickness of second lens group (mm)	1.80	Wide-angle end focal length fw (mm)	3.350

Table 10

Surface	Curvature radius (mm)	Distance (mm)	Refractive index ("d" line)	Abbe number
S1	R1 -105.256	D1 1.250	N1 1.50914	ν1 56.4
S2*	R2 3.725			
		D2 1.700		
S3	R3 ∞	D3 4.800	N2 1.58385	ν2 30.3
S4	R4 ∞			
		D4 variable		
S5*	R5 14.566	D5 1.800	N3 1.50914	ν3 56.4
S6	R6 -13.487			
		D6 variable		
S7	Aperture stop			
		D7 0.000		
S8*	R8 4.696	D8 2.500	N4 1.50914	ν4 56.4
S9	R9 93.726			
		D9 0.800		
S10	R10 10.987	D10 1.500	N5 1.58385	ν5 30.3
S11	R11 6.348			
		D11 0.900		
S12*	R12 13.654	D12 1.500	N6 1.50914	ν6 56.4
S13	R13 7.861			
		D13 variable		
S14	R14 ∞	D14 1.200	N7 1.51680	ν7 64.2
S15	R15 ∞			

* Aspheric

Table 11

Aspherical surface coefficient		Numerical data
S2 surface	ϵ	1.1291000
	D	$-0.1921580 \times 10^{-2}$
	E	0.1173390×10^{-3}
	F	$-0.9858780 \times 10^{-5}$
	G	$-0.1009840 \times 10^{-5}$
S5 surface	ϵ	32.1400000
	D	$-0.5846820 \times 10^{-3}$
	E	$-0.1789410 \times 10^{-3}$
	F	$-0.1522010 \times 10^{-4}$
	G	0.3046050×10^{-6}
S8 surface	ϵ	-0.5500000
	D	0.1140500×10^{-2}
	E	0.8869180×10^{-4}
	F	$-0.7484270 \times 10^{-5}$
	G	0.1166400×10^{-5}
S12 surface	ϵ	1.0000000
	D	$-0.6099420 \times 10^{-2}$
	E	0.6410210×10^{-4}
	F	0.8377440×10^{-5}
	G	0.1930490×10^{-5}

Table 12

	Wide-angle end	Middle position	Telephoto end
f (mm)	3.35 (fw)	5.00 (fm)	6.43 (ft)
D4 (mm)	7.395	3.443	1.394
D6 (mm)	1.000	3.663	4.382
D13 (mm)	0.957	2.245	3.575

(Back focus 1.00 mm)

5   In the above embodiment 3, lens depth D (lens 1 to prism 2) is 7.75 mm, total lens length (prism to image surface) H is 25.35 mm, total lens length (front S1 of lens 1 to image surface) is 28.30 mm, back focus (air conversion) is 2.75 mm – 4.04 mm - 5.37 mm, F number is 2. 89 - 3.43 - 3.97, and angle of view (2ω) is 61.1° – 39.9° – 31.0°, thus providing a compact, thin, and a high optical capability lens with all aberrations suitably corrected.